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Characteristics of organic matter in selected profiles from the Gezira Vertisols as determined by thermogravimetry

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A b s t r a c t. Some properties of soil organic matter (SOM) in Vertisols were studied in four profiles from the South, Central and North Gezira of Sudan using Thermogravimetry. The characteristics examined include the dynamics of weight loss, content of biodegradable and humified components of SOM and the proportions of these components in total organic matter. Differences were found between these components in relation to location of profile and horizon studied. The highest amounts of biodegradable components of SOM were found in South Gezira soil where both the clay content and the annual rainfall are highest with a systematic decrease northwards. A close positive correlation was found between the content of humified SOM and the clay content in soils. Comparing the continuously cropped sites with the permanent uncultivated non-cropped ones reveals that long termo-irrigation and continuous cropping has affected the quality of SOM in the soils studied.

K e y w o r d s: soil, Vertisol, organic matter, Sudan, thermogravimetry

INTRODUCTION

Soil organic matter (SOM) is known to affect the physical, chemical and biological properties of soils [8], and the Soil Survey Staff [14] considered soil organic matter to be the most important property of Vertisols changing considerably with depth. SOM has not been sufficiently studied in the Vertisols of the central clay plains of the Sudan. Investigations on these soils, carried out by different specialists, have included morphological and biological properties. Nevertheless, these soils have not been thoroughly studied with regard to the nature of their organic matter content and quality. The few studies dealing with this matter were confined to the determination of carbon and nitrogen and the C/N ratio was used as an indication of the quality of the organic matter of the soil, and the degree of humification.

The thermogravimetric soil analysis, used in this study was developed to describe soils in natural ecosystems and diagnose use-related changes [9,11]. The method is based on the dynamics of weight loss occurring when air-dry soil samples are heated from 25 to 1000°C. Data analysis at different temperature ranges provides information on the carbon, nitrogen, clay and carbonate contents [11] of samples using special application software that includes all published evaluation algorithms. It is also possible to determine biodegradable and humified components of soil organic matter and the content of bound water by weight losses in different temperature areas (200–450, 450–650, and 100–190°C, respectively). Indicator temperature ranges could be used so as to obtain results of the different components of SOM with minimum overlapping (for example: 280–290 and 510–520°C) [10,11]. Traditionally thermogravimetry was used to study the chemical properties and composition of humus.

In this study thermogravimetry was used to evaluate the biodegradability of SOM. Absolute quantities of biodegradable and humified components of soil organic matter as well as the relative amounts of these fractions to a total loss in SOM were determined in soils of the Gezira clay plains of the Sudan. The study also included a profile from a permanently fallow plot at the Gezira Research Station (GRS) farm in order to be able to assess the changes in quality of SOM resulting from continuous cropping and irrigation over more than 80 years.

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MATERIALS AND METHODS

Four soil profiles from the Sudan Gezira Vertisols were investigated. The selected profiles represent a transect from North to South in Gezira with an increase in rainfall intensity and clay content of the soil in the same direction. The soils of the Gezira are alluvial deposits of the Blue Nile. The depth of the deposited layer exceeds 20 m. At the GRS farm in Wad Medani in central Gezira, a plot was left permanently fallow to provide a piece of virgin land so that it may be used as a control against which changes in properties of soils resulting from long-term cropping could be monitored. A profile from this permanent fallow was included in the study so that changes in content and quality of soil organic matter resulting from continuous irrigation and cropping may be assessed. The sites selected for study are shown in Fig. 1, and the main characteristics of each site are summarised in Table 1.

Soil samples with a diameter of less than 2 mm were used for analyses. Particle size distribution was performed following the standard pipette method. Pre-treatment of soils with hydrogen peroxide or HCl was excluded because it was intended to use the clay fraction for mineralogical analysis. Salts were washed repeatedly to an electrical conductivity (EC) of soil suspension of 1:100 soil (w/v) : water was less than 100 $\mu S\ cm^{-1}$. Total carbon and nitrogen contents were measured by chromatography with the Carlo Erba CNS analyser. A separate determination of carbonates was achieved by ignition at 560°C followed by determination of the remaining carbon with the same CNS chromatographic method to determine the carbonate C. The pH and the soil electrical conductivity of the soils was measured in 1:5 soil (w/v) : water extract. For determination of cation exchange capacity (CEC) soluble salts were removed by 95% ethanol. The exchangeable cations were extracted

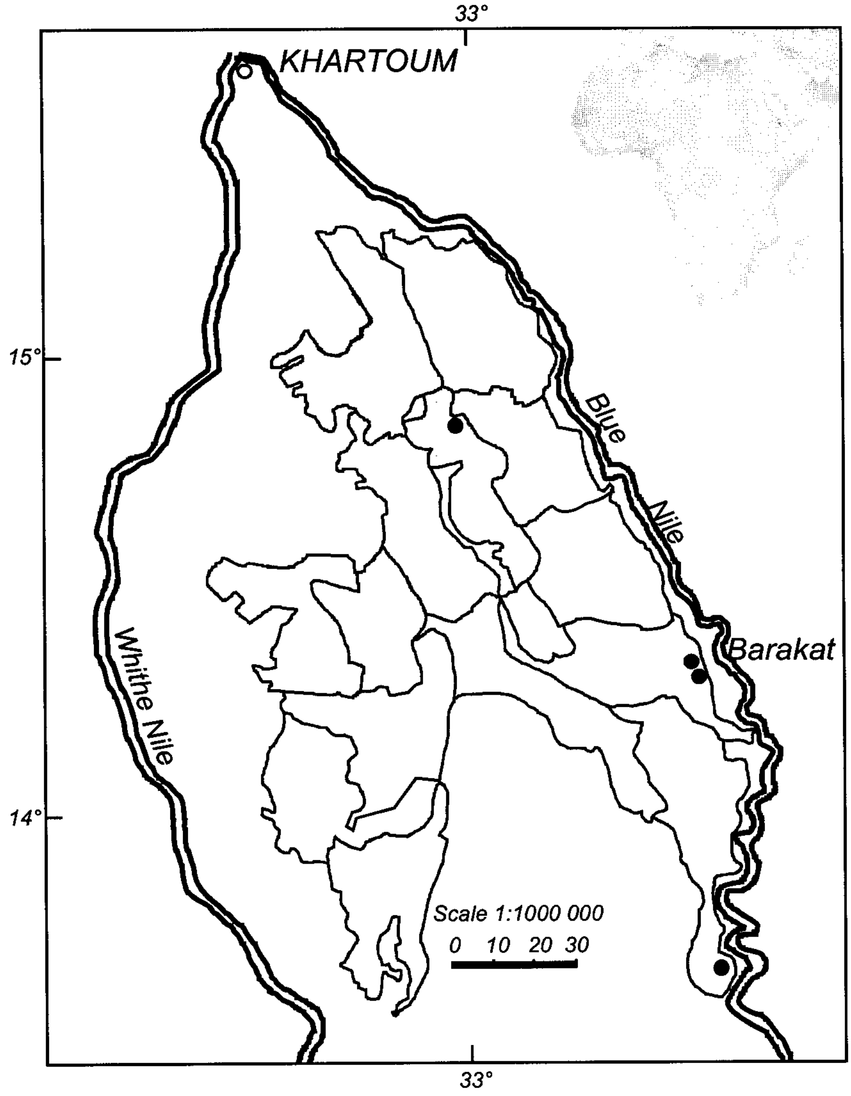

Fig. 1. Location of sites of the study in the Sudan Gezira.

T a b l e 1. Description of sites studied

Location	North	Central	South
Symbol	NG	GRS[1]	SG
Parent material	Blue Nile alluvial	Blue Nile alluvial	Blue Nile alluvial
Rainfall (mm) (annual)	292	354	430
Temperature °C (mean annual)	36.2	36.7	36.7
Physiography	plain	plain	plain
Slope	< 1%	< 1%	1%
Crop rotation	cotton, groundnuts, wheat, dura, fallow		
Last crop	fallow	wheat	fallow
Last irrigated	Oct. 1998	Feb. 1999	Oct. 1998

[1]PF is located in Central Gezira.

using 1 M NH_4Ac at pH=7. The ammonium exchanged was extracted as a measure of CEC by 1 M KCl at pH=7 after washing off excess ammonium with 95% ethanol.

For thermogravimetric analysis, the samples were additionally conditioned in an atmosphere of 76% relative humidity to compensate for differences in air-drying and in order to have comparable amounts of bound water. One gram of soil was taken in 0.9 ml crucibles. A thermogravimetric device STGA851[e] from Mettler-Toledo GmbH was used to record weight losses throughout the experimental range of the study. The heating process was carried out from 25 to 1000°C at a heating rate of 5°C min^{-1} in an air current at 25°C and 76% relative humidity. Details of the methods are found in Siewert [10,11].

In a difference from other reports about thermogravimetric studies of SOM [3,5,6,11,15] whole soil samples were used instead of extracted humic substances.

RESULTS AND DISCUSSION

General soil properties

The basic physical and chemical characteristics of the soils investigated are reflected in Table 2. The soils were clayey in texture with the profile NG having a clay content of less than 50, 52 to 61% clay in profile GRS and PF in central Gezira and 57 to 65% in profile SG. These results reflect a gradual increase in clay content from north to south in the region. Moisture regime and clay content were previously reported to have a dominant effect over temperature in the development of Vertisol's morphological properties under Sudan Gezira conditions. The CEC of studied soil correlates well with the soil content of clay [1]. In all these soils the C/N ratio was found to be lowest in the surface horizons of profiles examined in this study. That was associated with the higher content of nitrogen in the same horizons of cropped soils as compared to deeper horizons. This may be due to residual nitrogen from fertilisers added to the last grown crop. In the permanently fallow soil, the nitrogen content was not significantly higher at the surface than in the deeper horizons, but the C content was lowest in the surface horizon. Traditional agriculture in these soils has continued for the last 80 years and all parts of growing crops are removed with harvested crops. This provides part of the explanation why the organic matter content of these soils is too low.

The organic carbon content reflects the relative homogeneity of the whole soil profile. This relative similarity was the common denominator between different profiles examined in this study in relation to their content and organic matter. Comparing the contents of the organic carbon of the permanently fallow plot with those of the sites under cultivation it is evident that continuous cropping did not improve the organic matter content of Gezira Vertisols. Looking at the organic matter content at the bottom depths of profiles it is postulated that the SOM content in these soils represents soil material at the time of deposition. The higher C/N ratio at lower depths may indicate that the old soil organic matter was not easily decomposable. It is also important to note here that the vertical action churning process over thousands of years has led to the homogenisation of soils and hence the relative similarity between horizons at the same site. However, the increasing values of the salt content of the soils were noticed at depths around 70 cm, suggesting a limitation of effective self-mulching at that depth.

Dynamics of weight losses

The general trends to weight losses were more or less similar in all Vertisol samples. Therefore, the mean of weight losses from all samples of this study were compared with results from soils in temperate regions and presented in Fig. 2. It is interesting that in plotting dynamics of weight losses in Vertisols or those of the temperate zone soils, the shape of the curve is always the same and differences only exist in quantities.

T a b l e 2. Physical and chemical characteristics of soils

Depth (cm)	EC (μS cm^{-1})	pH	CEC (mM$_c$ kg^{-1})	Carbonate-C (g kg^{-1})	Organic-C (g kg^{-1})	Total N (g kg^{-1})	C/N ratio (OC)	Clay (%)
				Profile NG				
0–25	243	8.4	434	6.00	4.79	0.30	16.0	40
25–45	407	8.9	463	5.39	4.01	0.20	20.1	42
45–70	700	9.0	429	7.14	2.46	0.19	12.9	43
70–90	943	8.7	518	3.54	5.31	0.18	29.5	47
90–110	924	8.6	525	3.50	5.54	0.18	30.8	49
110–150	914	8.8	504	7.16	3.99	0.14	28.5	45
				Profile GRS				
0–10	325	7.4	594	5.29	6.35	0.34	18.7	52
10–35	275	8.4	626	5.15	5.44	0.23	23.7	55
35–65	490	8.9	618	5.05	4.79	0.19	25.2	56
65–85	731	8.7	621	4.51	5.96	0.18	33.1	55
85–115	1371	8.3	682	4.44	6.30	0.22	28.6	58
115–150	3605	7.6	679	5.34	6.43	0.22	29.2	58
				Profile SG				
0–3	651	7.4	691	5.72	7.50	0.43	17.4	57
3–35	406	8.5	631	10.75	4.99	0.26	19.2	58
35–88	597	8.6	720	7.79	6.00	0.24	25.0	59
88–110	1893	7.9	804	3.40	8.81	0.22	40.0	63
110–150	1895	7.7	784	4.70	8.38	0.24	34.9	65
				Profile PF				
0–7	301	8.3	669	5.99	4.00	0.25	16.0	52
7–35	345	8.5	658	5.78	4.61	0.22	21.0	57
35–65	433	8.8	601	6.10	4.67	0.19	24.6	57
65–90	676	8.7	585	4.69	5.77	0.21	27.5	59
90–120	2475	8.1	678	4.50	6.34	0.29	21.9	61
120–150	3970	7.9	671	5.25	6.05	0.18	33.6	61

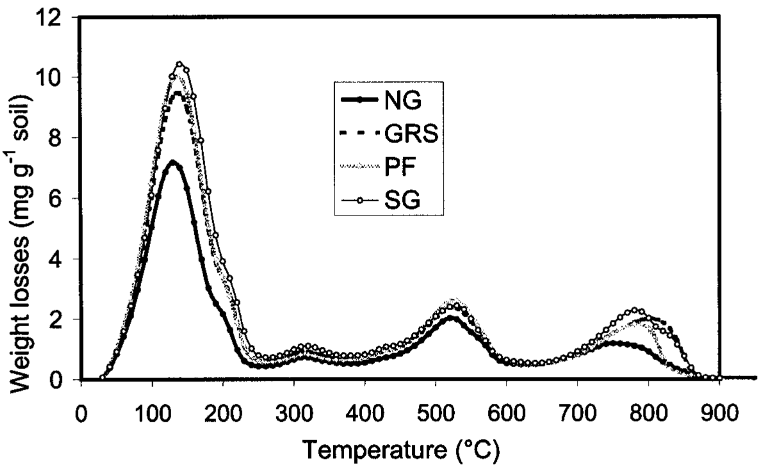

Fig. 2. Dynamics of weight losses in surface soil samples.

Vertisols have a higher content of bound water and carbonates, as expected. Higher losses of bound water can be attributed to the higher clay content of the Vertisols. In the temperature area of biodegradable components, a lower content of this component was found in Vertisols as compared to the temperate land soils. This could be related to the production of less vegetation Vertisols in comparison to the temperate regions. Humified components are associated with clay content and, hence, it was greater in the Vertisols. Regarding greater carbonates in the Vertisol soil, drier climate conditions prevailing in the region where they are formed explain the differences. However, weight losses relating to the organic matter in the range of 200–650°C are complicated by weight losses relating to destruction of clay minerals.

Amounts of biodegradable components of SOM

Figure 3 shows shares of biodegradable components in SOM. In the NG profile, the highest amounts of biodegradable soil organic matter were found in the surface horizon. In profile GRS in Central Gezira both absolute values of biodegradable components (Table 3) and the share of these components in the total SOM decreased from surface to deeper soil horizons. The losses of the biodegradable components of soil organic matter in GRS were higher than those found in NG profile. In profile SG the highest content of biodegradable SOM and the highest shares of biodegradable components in SOM were found in the surface horizon. The surface of the SG profile has the highest absolute value of biodegradable SOM and the highest shares when compared to NG and GRS profiles. The permanently fallow profile PF shows no difference between the different horizons in regard to the content of biodegradable organic matter except that the deepest layer of the profile (120–160 cm) has a value lower than in other layers. The share of biodegradable components in total SOM in this profile, as in other profiles, decreased with increasing depth. Profile PF has the lowest shares of biodegradable SOM in all horizons. This may be due to the irrigation and continuous cropping of the GRS plot. Thus cultivation in dry and warm conditions has opposite effects to cultivation in temperate climates [4,7]. The maximum amount of biodegradable SOM (0.88 mg g^{-1} soil) found in these profiles is very low when compared with those in soils from temperate climates under natural vegetation where values were in the range of 3 to 6 mg g^{-1} of soil [10].

Figure 4 is a plot of the content indicator of biodegradable SOM in the four surface horizons versus mean rainfall recorded. A clear trend was reflected in this plot, with increasing rainfall from North to South in Gezira the content of biodegradable SOM in soil increases. The content of biodegradable SOM in GRS plot was higher than in the permanently fallow plot. The North profile with the least rainfall has the lowest productivity of vegetation and, hence, the lowest content of biodegradable SOM followed by the GRS plot while the highest values were found in the South of Gezira. Although the permanently fallow plot lacks continuous irrigation the higher amounts of rainfall were sufficient to yield a higher content of biodegradable components than the content found in the northern profile but lower than the GRS plot. Thus rainfall is considered to be an important factor in the accumulation of biodegradable SOM under conditions of Gezira Vertisols. The effect of rainfall is confined to the surface horizons due to the nature of the heavy clay hindering penetration of water deep into the soil profile [2]. As mentioned earlier when shares of biodegradable components in soil organic matter were compared between horizons of different profiles there was no marked difference except in surface horizons. Also, when the surface horizons were compared between the profiles it was found that shares of biodegradable components of SOM in the profiles

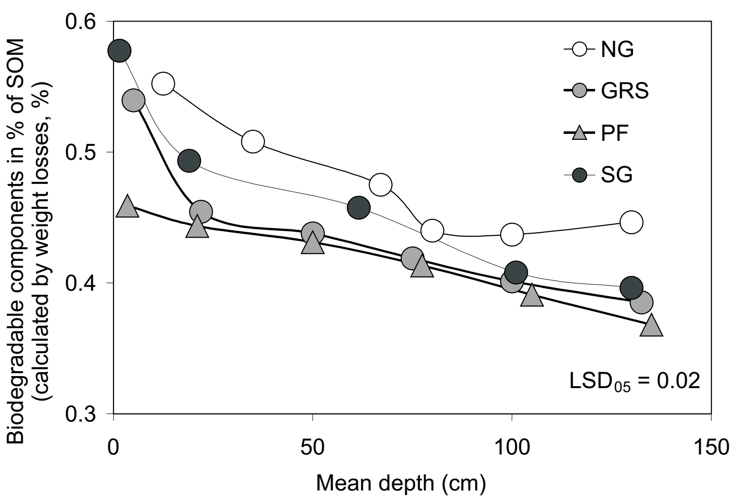

Fig. 3. Shares of biodegradable humus components in total loss of SOM in soil horizons.

T a b l e 3. Results of the thermogravimetric determination of soil components

Sample	Weight losses						
	Total (25–650°C)	Bound water (25–190°C)		Biodegradable SOM (200-450°C)		Humified SOM (450-650°C)	
	(mg g^{-1})	(mg g^{-1})	(% of total)	(mg g^{-1})	(% of total)	(mg g^{-1})	(% of total)
Profile NG							
0–25	123	65	63	18	15	24	19
25–45	130	69	53	16	13	24	19
45–70	133	70	53	16	12	26	19
70–90	138	78	56	17	12	28	20
90–110	145	80	55	18	12	29	20
110–150	156	80	51	17	11	30	19
Profile GRS							
0–10	166	86	52	26	16	28	17
10–35	164	91	56	24	15	28	17
35–65	163	91	55	22	14	28	17
65–85	162	93	57	23	14	29	18
85–115	171	97	57	23	14	30	18
115–150	176	102	58	25	14	31	18
Profile SG							
0–3	183	95	52	32	17	29	16
3–35	185	94	51	26	14	27	14
35–88	184	103	56	27	15	28	15
88–110	190	111	59	28	15	30	16
110–150	192	114	60	27	14	31	16
Profile PF							
0–7	166	92	55	25	15	29	18
7–35	162	90	56	25	15	29	18
35–65	166	93	56	24	14	29	18
65–90	176	98	56	27	15	31	18
90–120	178	106	56	27	15	32	18
120–150	185	107	58	22	12	31	17

of the continuously cropped soils in the north, south or central Gezira did not differ significantly. This is due perhaps to the fact that the climatic effects on biodegradable SOM are accompanied with a similar effect on humified organic substances and hence the proportions are not affected. Significant differences were found between the values of biodegradable SOM of the three horizons of the irrigated plots on the one hand and the surface horizon of the permanently fallow plot on the other ($p < 0.001$).

Correlations between selected components of SOM

Bound water index values were found to be positively correlated with humified components of SOM index (R^2= 91%). This is surprising as bound water is usually reported to be correlated with the clay content of soils [8]. However, the correlation coefficient between the bound water index and clay content was also positive (R^2=95%). This may validate the conclusion that humified organics in Vertisols are positively correlated with their clay content [4,7]. This correlation was found to exist (R^2= 85%).

CONCLUSIONS

The quality of different components of the organic soil matter studied in Vertisols using thermogravimetry has revealed significant differences between these components in relation to location in the Gezira region and in relation to land use. The content of biodegradable SOM differs between soils with a clear trend of increasing values in the surface horizons from North to South of Gezira. Humified components of SOM were found to be positively correlated with clay content. Properties related to the quality of SOM in Gezira Vertisols may be explained by the prevailing climatic conditions, mainly by rainfall, as temperature differences between sites are minimal.

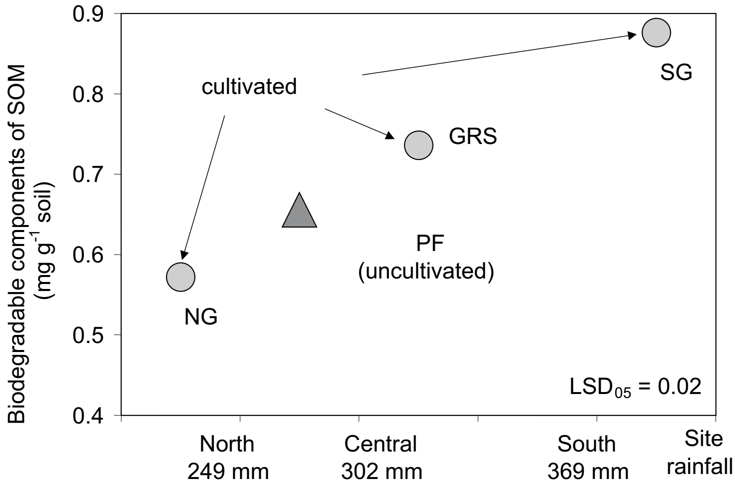

Fig. 4. Biodegradable SOM in the four surface horizons verus mean rainfall recorded.

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REFERENCES

1. **Elias E.A., Salih A.A., and Alaily F., 2001.** A study of cracking in Vertisols from the Sudan Gezira. Int. Agrophysics, 15, 151–155.
2. **Farbrother H.G., 1972.** Field behaviour of Gezira clay under irrigation. Cotton Growing Review, CRC London, 49.
3. **Končic V.A. and Černikov V.A., 1977.** Differential thermogravimetric analyses of humic acids, extracted with different methods (in Russian). Izv. TSCHA, Moskva, 2, 88–98.
4. **Körschens M., Weigel A., and Schulz E., 1998.** Turnover of soil organic matter (SOM) and long-term-balances – tools for evaluating sustainable productivity of soils. Z. Pflanzenernähr. Bodenk., 161, 409–424.
5. **Leineweber P. and Schulten H.-R., 1992.** Differential thermal analysis, thermogravimetry and pyrolysis-field ionisation mass spectrometry of soil organic matter in particle-size fractions and bulk soil samples. Thermochimica Acta, 194, 175–187.
6. **Peschke H., Kretschmann S., and Zeise S., 1991.** Thermogravimetrische Untersuchung von Huminsäurepräparaten aus Böden kohlenstoffextremer Prüfgliedpaare statischer Dauerversuche. Archiv für Acker- und Pflanzenbau und Bodenkunde, 35(1), 49–55.
7. **Rasmussen P.E., Goulding K.W.T., Brown J.R., Grace P.R., Janzen H.H., and Körschens M., 1998.** Long-term agroecosystem experiments: assessing agricultural sustainability and global change. Science, 282, 893–896.
8. **Scheffer F. and Schachtschabel P., 1989.** Lehrbuch der Bodenkunde, Ferdinand-Enke-Verlag, Stuttgart.
9. **Siewert C., 1995.** Ecosystem-oriented base for the determination of humus quality. Part 3. Methodological base. Changes in thermogravimetric characteristics of soil of soil organic matter by biological Transformations. Arch. Acker Boden, 139, 53–68.
10. **Siewert C., 1996.** Untersuchungen zur thermischen und biologischen Stabilität der organischen Bodensubstanz. DFG-Forschungsbericht zum Projekt Si488 1–2, Berlin.
11. **Siewert C., 1998.** Verfahren zur Verfahren zur Bestimmung der qualitativen Zusammensetzung der organischen Bodensubstanz von Mineralböden. Patentschrift DD - GO1 N 196 38 731.
12. **Siewert C., 2001.** Investigation of the Thermal and Biological Stability of Soil Organic Matter. Shaker-Verlag, ISBN 3-8265-9631-5.
13. **Ševcova L.K. and Sidorina S.I., 1988.** Influence of long term fertilization on thermogravimetric properties of humic acids (in Russian). Počvovedenie, 6, 130–136.
14. Soil Survey Staff, **1975.** Soil taxonomy. A basic system of soil classification for making and interpreting soil surveys. Agriculture Handbook No. 436. Soil Conservation Service, USDA, Government Printing Office, Washington, D.C.
15. **Travnikova L.S., 1985.** Experiences with thermogravimetric analyses of soil organic matter in different mineral grain fractions (in Russian). Fiziko-chimiceskie aspekty pocvennogo plodorodija. Naucn. tr. pocv. in-ta im. Dokucaeva, Moskva, 15–22.